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Purpose of this document

To meet the overall LAT reliability, an allocation of 0.96 has been assigned to the ACD subsystem. This is understood as the probability that the ACD will meet all its Level 3 requirements at 5 years. Tony Diventi has performed a reliability analysis for the ACD subsystem, with inputs from the ACD team. These inputs include details of the design of the detectors from Alex Moiseev. The driving Level 3 requirement is the 0.9997 detection efficiency, averaged over the ACD (excluding the back-most row of side tiles). The reliability analysis is complex, but to first approximation it can be understood as having two dominant components:

1. The probability that a tile will be made inoperative by micrometeoroid penetration of the shield. For that analysis, any penetration through the shield and the tile wrapping constitutes tile failure since the tile will no longer be light tight. [It is not worth considering the small measure of cases in which penetration has happened but adequate light tightness is maintained.]
2. The probability that one of the components of the electronics chain (PMT, front end electronics, digital electronics) will fail.

Of these two, the first is the most significant. The primary assumption in that analysis is the micrometeoroid distribution. For PDR, the distribution specified in the IRD (Orbital Debris Engineering Model, ORDEM96) was used. With that assumption, the penetration probability at 5 years is 0.03 (reliability 0.97).

After PDR, an updated micrometeoroid distribution (ORDEM2000, see http://ston.jsc.nasa.gov/collections/TRS/_techrep/TP-2002-210780.pdf) became available, and a modification to the IRD was proposed to include the new information. Using ORDEM2000, the penetration probability grows by a surprisingly large factor, to 0.14, shrinking the reliability to 0.86. Some of the differences between the models are described on p46 in the ORDEM2000 document referenced above and in PPT slides from Eric Christiansen and Jeanne Crews of Johnson Space Center dated 18 September 2002. At face value, this single change obviously causes a failure of the ACD design to meet its reliability requirement.

This document reexamines the relevant aspects of the flow of the reliability requirement into the ACD design, motivated by the new information and the pending change to the IRD. Justification is provided for defining how many penetrations of the micrometeoroid shield constitute a failure.

Distributed vs. localized ACD inefficiencies and their impacts

The primary function of the ACD is to provide a segmented, approximately hermetic, relatively inexpensive charged particle detector. The information from the ACD is primarily (but not exclusively) used in conjunction with tracking information: if a charged particle track points to an ACD tile, the event is vetoed. The details of the use of the ACD information change with the amount of energy deposited in the calorimeter, for several reasons that are not particularly relevant here. The Level 3 requirement of 0.9997 efficiency was first derived by Jonathan Ormes, based on an analysis of the rejection of the cosmic ray electron background around 10 GeV (where this background fraction is greatest). Although the hadronic background fluxes are larger, they also have fundamentally different characteristic interactions in the calorimeter, compared with those of gamma rays. Assuming one order of magnitude rejection from TKR information alone, the resulting required ACD rejection efficiency is 0.9997.

The inefficiency of the ACD to detect charged particles is due to two qualitatively different effects[1]: (1) the intrinsic inefficiency of the active sensors plus readout, and (2) gaps between active sensors. The first is a distributed inefficiency, while the second is localized. Both effects are taken into account in the simulations.

When the ACD information is used in conjunction with information from the TKR to reject background, distributed inefficiencies are much more problematic than localized inefficiencies. This is because localized inefficiencies can be accommodated with relatively small fiducial cuts based on TKR information, with modest loss of

[1] The distinction between these two effects blurs somewhat at the edges of the tiles, of course, but those details have been taken into account in the simulations.

effective area. On the other hand, little can be done to handle large distributed inefficiencies beyond making much more severe fiducial cuts that remove large perimeter volumes of the instrument. Thus, if the functional regions of the ACD have 0.9997 efficiency, a localized gap will not have a drastic effect.

In this context, we consider the effects of micrometeoroid penetration causing tile loss. Such an event would clearly cause a localized inefficiency in the ACD. A simple FMEA was performed prior to PDR to quantify the effects of a lost tile on the operation of the LAT. A lost tile would potentially have an impact on two aspects of operations: (1) elevated L1 trigger rate if the ACD throttle option is turned on (in the nominal running mode, the ACD information is not used at L1 so there is no impact) and (2) reduced onboard software filter rejection efficiency. For (1), with the throttle turned on, the orbit-averaged L1 trigger rate was 1.8 kHz with a full ACD; removing either the center top tile or a corner top tile increased the rate by only about 100 Hz. The impact is not significant. For (2), using the strawman filter concept developed for PDR, the nominal 17 Hz post-filter rate (which included all background sources) increased to 27 (24) Hz when the top center (corner) tile was removed. A simple mitigation was then implemented by requiring that a track does not start in the silicon layer directly underneath the tile. [An even simpler mitigation would remove triggers that had an XY coincidence in that layer.] That reduced the post-filter rate back to 19 (17) Hz when the top center (corner) tile was removed. Thus, losing a single tile will not severely impact the realtime operation of LAT. The impact on the ultimate background rejection is more difficult to study quantitatively. A full study would require generating $O(10^7)$ background events. However, we can estimate the impact on the effective area by making simple fiducial selections (if a tile is actually lost during the mission, the mitigations will be significantly more sophisticated and effective). The simplest analysis is to view the TKR layers as fantastically (spatially) precise, but leaky, ACDs. The worst case of area*solid angle would be for the loss of the top center tile. At normal incidence, there is about 12% dead area in each TKR layer, averaged over the whole face. However, the center tile covers a particularly dead region, which we'll conservatively take to be 20% uninstrumented. Thus, by removing events with tracks that start in the front-most six layers of the four center towers, the effective rejection efficiency of the ACD can be recovered, with a resulting <~10% loss in effective area. The peak effective area at PDR was 10,000 cm^2, and the SRD requirement is >8,000 cm^2, so even a 10% loss, while painful, will still result in LAT meeting the requirements. Again, it is important to emphasize that this rejection will be done on the ground, where a much more sophisticated analysis can be performed, addressing the specific failure configuration, energy dependence, and science.

Losing more than one tile would likely have more serious impacts. It is difficult to analyze this quantitatively, because of combinatorics (which two tiles?). However, loss of two tiles, particularly on two separate faces of the ACD, would provide an entrance and exit path over a large area*solid-angle for background. It is likely that LAT could still operate, but the ultimate background rejection would likely be compromised to the point of reducing the effective area to a level that does not meet the requirement. Good science could still be done, of course, and the mission would still be very valuable, but this is a situation we want to avoid.

In summary, it is possible for LAT to operate and to meet all science requirements in the event of loss of one (but probably not more than one) tile.

Impacts of material in the field of view

Material in the field of view of the LAT that resides outside of the ACD tiles has two impacts on LAT performance.

1. Photons convert in the material, reducing the flux that can be measured well within the LAT sensitive volume. According to the information provided at the ACD CDR, the current micrometeoroid shield/thermal blanket constitutes about 0.8% r.l. of material. The total ACD material (including supports) constitutes about 6% r.l.
2. Cosmic rays interact in the material, in rare cases producing gamma rays. This effect was measured by the EGRET team at a beam test at Brookhaven prior to GRO launch, since it was not easy to calculate. According to the EGRET calibration paper (ApJS86(1993)), $O(10^{-6})$ photons/proton incident on the blanket were produced (though the results were dominated by systematic uncertainties related to the beam). There are some mitigating design features in the LAT (planar geometry and the "crown" in the front); however, since GLAST is expected to resolve ~half of the extragalactic diffuse flux, the material outside the ACD should be kept to a minimum consistent with adequate micrometeoroid protection. Dave Thompson warns that COS-B was limited by this problem.

For both these reasons, the material outside of the tiles should be minimized.

Requirements flow

Since LAT can meet the requirements with one non-functional ACD tile, provided the efficiency is maintained in the rest of the system, it is justified to flow the reliability requirement to the micrometeoroid shield taking this into account.

Risk mitigation

After the ORDEM2000 modification to the IRD was proposed, the ACD team developed a mitigation plan to increase the thickness of the micrometeoroid shield. If the ORDEM2000 estimate is verified to be correct, the 0.14 penetration probability seems a bit worrisome: assuming uncorrelated events (randomized orbital junk), there is a 2% chance that more than one tile will be disabled at 5 years. While that is formally acceptable, we should consider improving the thickness of the shield, particularly around the sides. The additional attenuation of the flux around the sides, but not the front, minimizes the impact on the field of view and effective area, and – more importantly – given the anticipated observing strategy, the sides will by far most often face the ram direction, thereby having the highest probability of impact.